ANGULAR CORRELATION MEASUREMENTS

Studies of relative transition probabilities of gamma radiation and of Internal Compton Effect. Experiments on nuclear g-factors.

By

TORSTEN LINDQVIST

UPPSALA 1957
ALMQVIST & WIKSELLS BOKTRYCKERI AB

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INAUGURAL DISSERTATION

by

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Fil. lic., Värml.

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The probability of emission of nuclear radiation depends in general on the angle between the nuclear spin axis and the direction of emission. Under ordinary circumstances, however, the total radiation from a radioactive source is isotropic, because the nuclei are randomly oriented in space. Anisotropic radiation can be observed only if the nuclei are not randomly oriented.

A method of getting such oriented nuclei consists in picking out only those nuclei whose spins happen to lie in a preferred direction. This can be done if the nuclei decay through successive emission of two radiations (e.g. a gamma cascade). The observation of the first radiation in a fixed direction selects those nuclei, which have their spins in certain directions. The succeeding radiation then has a definite angular correlation with respect to the first radiation.

Experimentally one measures the number of coincidences between the two radiations as a function of the angle θ between the two detectors. The numbers of coincidences then give the correlation function $W(\theta)$. The comparison of $W_{\text{exp}}(\theta)$ with theory finally provides information about the nuclear properties.

The angular correlation experiments described below were concerned with four problems:

(*a*) The angular correlation is very sensitive to mixtures of different multipolarities in the radiation. Usually one finds mixtures of quadrupole and dipole radiations. By means of angular correlation experiments it is possible to determine the mixing ratio with high accuracy. The mixing ratio gives the relative gamma transition probabilities, from which important conclusions about the nucleus can be drawn.

(*b*) The angular correlation function depends on the spins of the nuclear levels involved in the gamma cascade. If one of these spins is known from some other measurements, it is in general possible to determine the two other spins by an angular correlation experiment.

(*c*) If the intermediate level of the gamma cascade has a lifetime in the region 10^{-7}s–10^{-9}s, there is a possibility of determining the nuclear g-factor of this level by means of angular correlation measurements. Under the influence of an external magnetic

field the angular correlation pattern is attenuated and rotated. Classically one can say that the magnetic field produces a precession of the nuclei around the symmetry axis. By studying the anisotropy as a function of the magnetic field it is possible to determine the nuclear g-factor. The magnetic field required for observing an attenuation of the anisotropy is of course a function of the lifetime of the intermediate level. The shorter the lifetime the stronger the field. If it is assumed that $g = 1$, one can show that a lifetime of 10^{-8}s requires 10^4 gauss. Accordingly a lifetime of 10^{-9}s requires 10^5 gauss. Unfortunately there are very few cases with lifetimes in the region 10^{-7}s–4×10^{-9}s. This region should require magnetic fields up to 25000 gauss, which is easily obtained without extraordinary arrangements. In order to reach the region of lifetimes shorter than 4×10^{-9}s, in which region one finds the wellknown rotational levels, one has to make special arrangements.

(*d*) There are other nuclear deexitation processes than gamma cascades. One example is the Internal Compton Effect, in which there is a simultaneous ejection of a bound electron and emission of a gamma quantum. For the identification of such a process the angular correlation of the gamma quanta with respect to the electrons is very important.

The experiments are reported in the following articles:

I. Torsten Lindqvist, Gamma-gamma angular correlations in Ca^{43}, Hg^{200}, and Pb^{206}. *Arkiv för Fysik 12*, 495 (1957).

II. Torsten Lindqvist and Ingvar Marklund, The influence of l-forbiddenness on magnetic dipole transitions in Tl^{203}. *Nuclear Physics 3*, 367 (1957).

III. Torsten Lindqvist and Ingvar Marklund, Mixing ratios of 2^+–2^+ transitions in some even nuclei. *Nuclear Physics 4*, 189 (1957).

IV. Torsten Lindqvist and Ernst Heer, Directional correlation measurements in Fe^{57}. *Nuclear Physics 2*, 680 (1956/57).

V. T. R. Gerholm, T. Lindqvist, and H. de Waard. Multi-coincidence goniometer for angular correlation measurements. *Nuclear Instruments 1*, 107 (1957).

VI. Torsten Lindqvist and Erik Karlsson, Applications of a multi-channel goniometer. *Arkiv för Fysik 12*, 519 (1957).

VII. Torsten Lindqvist, Bo-Göran Pettersson, and Kai Siegbahn, The Internal Compton Effect. A determination of cross section and angular correlation. *Nuclear Physics 4*, 1 (1957).

In I is described an automatic apparatus for angular correlation measurements with two detectors (Fig. 1). Further a complete description is given of the methods of measurement, of the treatment of data and the corrections necessary. Correlation experiments of cascades in Ca^{43}, Hg^{200} and Pb^{206} determine spins of excited states in the nuclei.

The determination of mixing ratios of the transitions in Tl^{203} is described in II. The gamma cascade is of special interest, because the second transition is an orbital

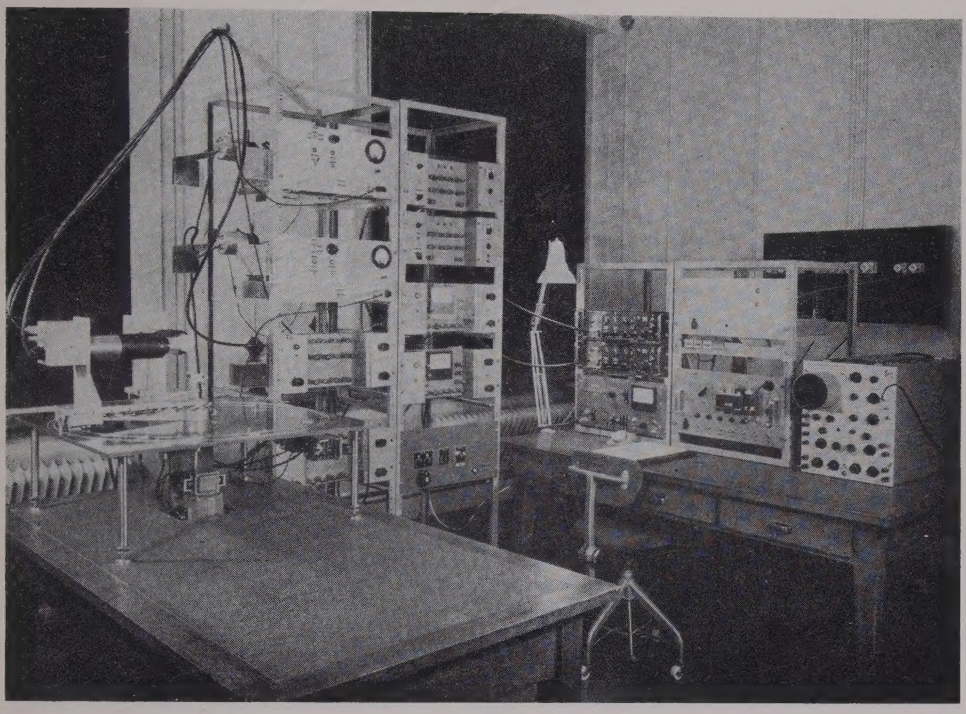

Fig. 1.

momentum forbidden (l-forbidden) magnetic dipole transition, while the first is l-allowed. From the mixing ratios of the transitions it is possible to determine the strength of forbiddenness.

The even-even nuclei are well suited for angular correlation experiments, because one can easily find a cascade, in which the second transition is a pure $E2$ radiation. Thus only the first transition can be mixed, which reduces considerably the number of possible interpretations of the measured correlation. Angular correlation experiments in this type of nuclei are described in III. Interesting conclusions about the type of excitation in these nuclei were drawn.

In IV is described a correlation experiment in Fe^{57}. The second transition of the cascade was of very low energy (14 keV), which made special detector arrangements necessary. Mixing ratios of the cascade were determined.

In order to obtain a good statistical accuracy it is necessary to run the correlation experiment for a certain total recording time. This recording time can be considerably reduced if one uses four detectors instead of two detectors. Such an apparatus is

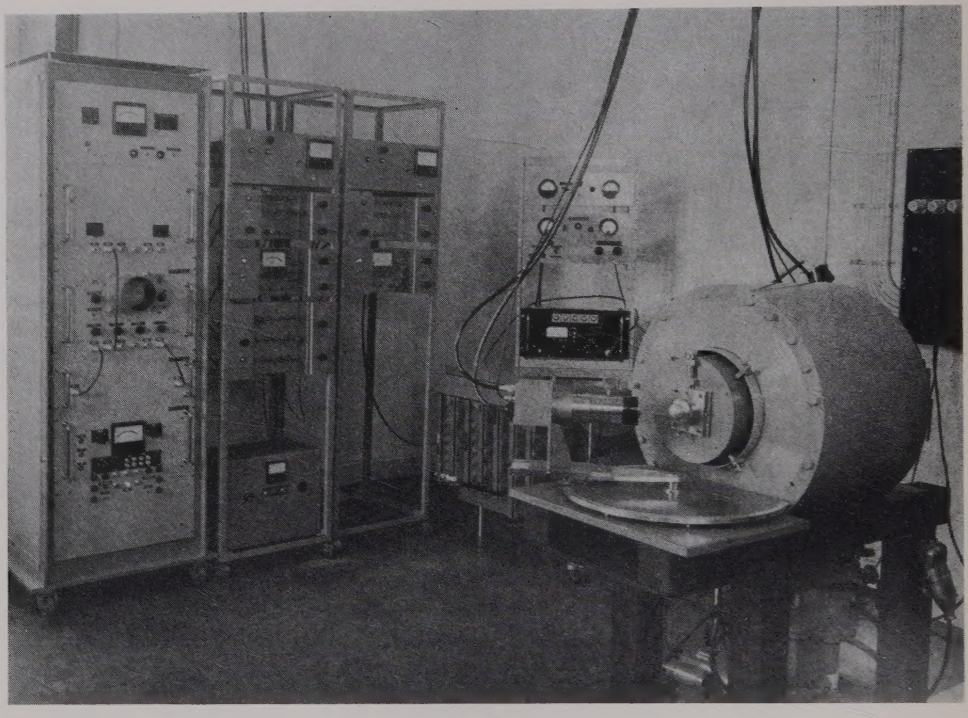

Fig. 2.

described in V, which is mainly an electronic description. In VI more details about the measurements are given together with applications.

In VI are also described experiments on nuclear g-factors in Ta^{181} and in Pm^{147}. In the latter case only an upper limit could be measured.

The experiment on the Internal Compton Effect is described in VII. For this investigation a newly designed beta-gamma coincidence spectrometer (Fig. 2) was used. A determination of the cross section as well as of the angular correlation was carried out.

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